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A COMPARISON OF FREQUENCY-DOMAIN APPROACH AND TIME-DOMAIN APPRO--ETC(U)

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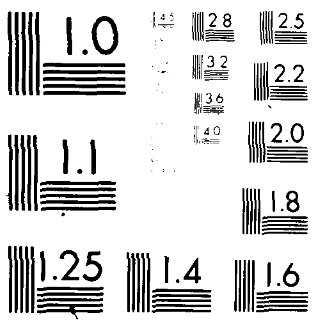

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A COMPARISON OF FREQUENCY-DOMAIN APPROACH
AND TIME-DOMAIN APPROACH: A Case Study of
Fault Analysis of Analog Circuits

by

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Technical Report No. EE-802

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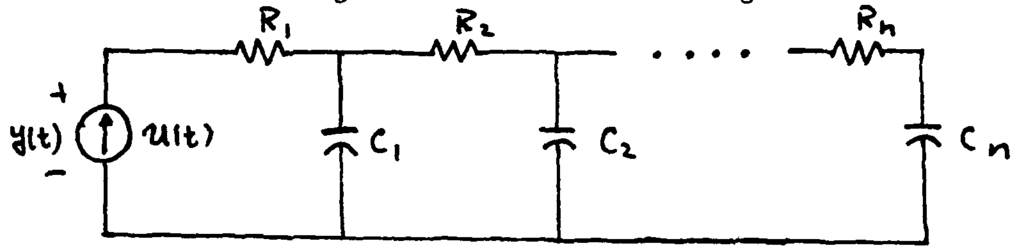
I. Introduction

There have been considerable efforts expended in analog fault analysis. Most of them [1], [2], [3] employ frequency-domain approach, i.e., diagnosing faulty components from measured transfer function, while few [5] use time-domain approach to isolate faults by means of Markov parameters. Theoretically, both approaches are still under development and all seem feasible. It is the purpose of this report to compare these two approaches numerically by simulation on RC ladders. In this example, it is shown that the time-domain approach is far better than the frequency-domain approach.

II. Simulation and Results

Consider an n-stage RC ladder as shown in Figure 1.



The impedance $Z(s)$ of this RC-ladder has the form

$$Z(s) = \frac{a_0 s^n + a_1 s^{n-1} + \ldots + a_n}{s^n + b_1 s^{n-1} + \ldots + b_n}$$

Since there are only $(2n+1)$ coefficients to be determined, we need only to measure the impedance $Z(s_i)$ at $(2n+1)$ different sampling frequencies, s_i, $i = 1,2,\ldots,(2n+1)$.

Once $Z(s)$ is obtained, it can be expressed as

$$Z(s) = R_1 + \cfrac{1}{C_1 s + \cfrac{1}{\vdots\; R_i + \cfrac{1}{C_i s + \cfrac{1}{\vdots\; R_n + \cfrac{1}{C_n s}}}}}$$

and values of components can be calculated as

$$\begin{aligned}
R_1 &= \lim_{s\to\infty} \frac{N_1(s)}{D_1(s)} \\
C_1 &= \lim_{s\to\infty} \frac{D_2(s)}{N_1(s)} && (1) \\
R_i &= \lim_{s\to\infty} \frac{N_i(s)}{D_i(s)} \\
C_i &= \lim_{s\to\infty} \frac{D_{i+1}(s)}{N_i(s)} && i = 2, 3, \ldots, n
\end{aligned}$$

where

$$N_1 = \text{numerator polynomial of } Z$$

$$D_1 = \text{denominator polynomial of } Z$$

$$N_i = N_{i-1}(s) - C_{i-1} \cdot D_i(s)$$

$$D_i = D_{i-1}(s) - R_{i-1} \cdot N_{i-1}(s)$$

On the other hand, the ladder has a state equation expression

$$\dot{\underline{x}} = A\underline{x} + Bu$$

$$y = C\underline{x} + Du$$

where $\underline{x}$ are the capacitor voltages, u the terminal current, y the terminal voltage and

$$\left[\begin{array}{c|c} A & B \\ \hline C & D \end{array}\right] = \left[\begin{array}{cccccc|c} -\frac{1}{R_2C_1} & \frac{1}{R_2C_1} & & 0 & & & \frac{1}{C_1} \\ +\frac{1}{R_2C_2} & \left(\frac{-1}{R_2C_2} - \frac{1}{R_3C_2}\right) & & \frac{1}{R_3C_2} & \ddots & & 0 \\ & \ddots & \ddots & \ddots & & \frac{1}{R_nC_{n-1}} & \vdots \\ & 0 & \ddots & \ddots & \ddots & & \vdots \\ & & & & \frac{1}{R_nC_n} & \frac{-1}{R_nC_n} & 0 \\ \hline 1 & 0 & \cdots & & & 0 & R_1 \end{array}\right] \tag{2}$$

The Markov parameters are given by

$$\begin{aligned} m_0 &= D \\ m_1 &= CB \\ m_2 &= CAB \\ &\vdots \\ m_k &= CA^{k-1}B \\ &\vdots \\ m_{2n} &= CA^{2n-1}B \end{aligned} \tag{3}$$

which can be measured by a method developed by Liu and Suen [5].

Once the Markov parameters, m_i, $i = 0,1,\ldots,2n-1$, are obtained, the circuit parameters R's and C's can be solved from the simultaneous equations(2) and (3).

In this simulation, it assumes no measurement error for both $Z(s)$ and m_i's . They are exact. We want to find the numerical error generated by solving (1) and (3).

Ladders of four and six stages were chosen, transfer functions and A, B, C, D parameters were calculated using nominal values of components. Then, as a way of comparison, the significant digits of coefficients of transfer function and entries of A, B, C, D were reduced before we performed the manipulation by these two methods. The results are listed in Tables 1 and 2.

It is clear from the tables that, as significant digits decrease, the estimated values of frequency-domain method stray away from nominal values gradually, then collapse abruptly at a certain point and become unrealizable, i.e., some of the values become negative. On the contrary, the results of the time-domain method remain about the same order of accuracy as parameters of state equation.

The discrepancies may be due to the following reasons:

1) The frequency-domain approach deals with computations of complex numbers while the time-domain approach deals with computations of real numbers.

2) The given circuit is sequentially-linear for the time-domain approach [5,6]. This can be demonstrated by the 4-stage RC ladder. Solving (2) and (3), we have

$$m_0 = R_1$$
$$m_1 = \frac{1}{C_1}$$

$$m_2 = -\frac{1}{R_2 C_1^{\,2}}$$

$$m_3 = \frac{1}{R_2^{\,2} C_1^{\,2}}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)$$

Therefore, R_1, C_1, R_2, C_2 can be solved sequentially by a set of <u>linear</u> equations,

$$R_1 = m_0$$

$$C_1 = \frac{1}{m_1}$$

$$R_2 = -\frac{1}{m_2 C_1^{\,2}}$$

$$\frac{1}{C_2} = m_3 R_2^{\,2} C_1^{\,2} - \frac{1}{C_1}$$

III. Conclusion

This simulation strongly suggests that time-domain approach is more data-tolerant than frequency-domain approach in the sense that no sudden breakdown occurs and component values can be estimated with reasonable accuracy when the measurement is not accurate enough or where the noise must be taken into consideration. Thus, though it is still too early to have definite conclusion, time-domain approach seems to be a more promising method in attacking fault diagnosis problem.

Simulation on 4-stage RC Ladder

	Time-Domain Method				Frequency-Domain Method			
	R_1 C_1	R_2 C_2	R_3 C_3	R_4 C_4	R_1 C_1	R_2 C_2	R_3 C_3	R_4 C_4
Nominal Values	2.2 .015	47 .47	8.2 .01	1 .022	2.2 .015	47 .47	8.2 .01	1 .022
Significant Digits 10	2.2 .015	47 .47	8.2 .01	1 .022	2.2 .015	47 .47	8.2 .01	1 .022
8	2.2 .015	47 .47	8.2 .01	1 .022	2.2 .015	47 .46597	1.3587 .0056867	7.7603 .030347
7	2.2 .015	47 .47	8.2 .01	1 .022	2.2 .015	47.005 .70919	-.018072 -.23768	9.1305 .030482
6	2.2 .015	47 .47	8.2 .01	1 .022				
4	2.2 .014999	47.017 .46982	8.2044 .0099962	1.0003 .021997				
2	2.2 .014925	47.857 .46434	8.4454 .0096776	1.0569 .020555				

Table 1: In the frequency-domain approach, the calculated values of R_3 and C_3 become negative when the significant digits are reduced to 7. No such discrepancies in the time-domain approach.

Simulation on 6-Stage RC Ladder

	Time-Domain Method						Frequency-Domain Method					
	R_1	R_2	R_3	R_4	R_5	R_6	R_1	R_2	R_3	R_4	R_5	R_6
	C_1	C_2	C_3	C_4	C_5	C_6	C_1	C_2	C_3	C_4	C_5	C_6
Nominal	15	220	39	75	8.2	100	15	220	39	75	8.2	100
Values	.0022	.001	.015	.022	.0047	.01	.0022	.001	.015	.022	.0047	.01
Significant Digits	15	220	39	75	8.2	100	15	220	39	75	8.206	99.994
10	.0022	.001	.015	.022	.0047	.01	.0022	.001	.015	.022004	.004696	.01
8	15	220	39	75	8.2	100	15	220	39	75.027	8.9232	99.25
	.0022	.001	.015	.022	.0047	.01	.0022	.001	.015	.022436	.0042666	.0099976
7	15	220	39	75	8.2	100	15	220	39.003	74.992	8.0302	100.18
	.0022	.001	.015	.022	.0047	.01	.0022	9.9994E-4	.015	.021883	.0048168	.010001
6	15	220	39	74.999	8.1999	100	15	219.98	39.023	77.659	-.67597	106.2
	.0022	.001	.015	.022	.0047001	.0099997	.0022	.0010004	.015015	-.022917	.049583	.010019
4	15	219.99	38.988	74.908	8.1865	100.16						
	.0022002	.0010001	.015011	.022036	.0047074	.0099507						
2	15	214.29	37.815	75.63	8.6555	120.64						
	.0022222	.001037	.015256	.021107	.0044222	.0073993						

Table 2: In the frequency-domain approach, the calculated values of C_4 and R_5 become negative when the significant digits reduced to 6. No such discrepancies in the time-domain approach.

References

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